Absorption spectral structure in highly charged zirconium plasmas in water window soft x-ray spectral region

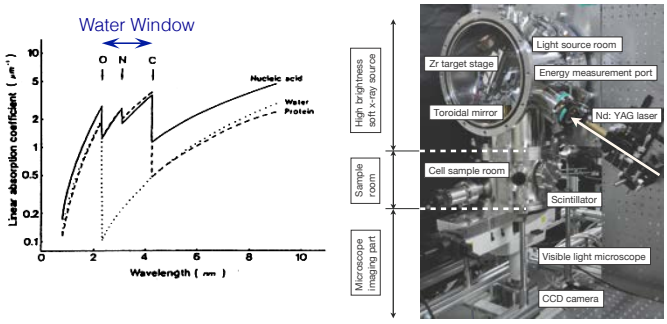
Takanori Miyazaki[1,2], Goki Arai[2], Hiroyuki Hara[2], Thanh-Hung Dinh[2], Takeshi Higashiguchi[2], Akinobu Irie[2], Chihiro Suzuki[3], Daiji Kato[3], Akira Sasaki[4], Padraig Dunne[1], and Gerry O'Sullivan[1]

[1]University College Dublin, 2Utsunomiya University, [3]National Institute for Fusion Science, [4]Quantum Beam Science Center, Japan Atomic Energy Agency

Contact e-mail: takanori.miyazaki.cst@gmail.com

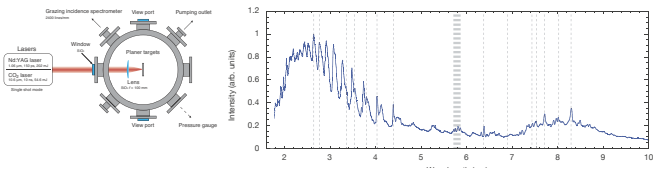
1. Introduction

We have investigated the absorption spectral structure of laser-produced highly charged zirconium plasmas in the water window soft x-ray spectral region. Structure due to absorption, which originates from opacity effects in the recombination phase, was observed at a delay time of around 100 ns.



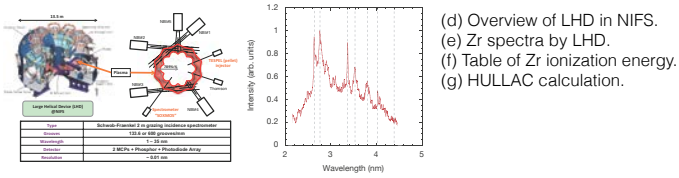
2. Spectral structures of Zr plasmas

A. Single pulse LPP experiment



(a) Experimental setup.
(b) Zr spectra by single pulse Nd:YAG laser.
(c) ZrO_2 spectra by single pulse CO_2 laser.

B. LHD experiment



(d) Overview of LHD in NIFS.
(e) Zr spectra by LHD.
(f) Table of Zr ionization energy.
(g) HULLAC calculation.

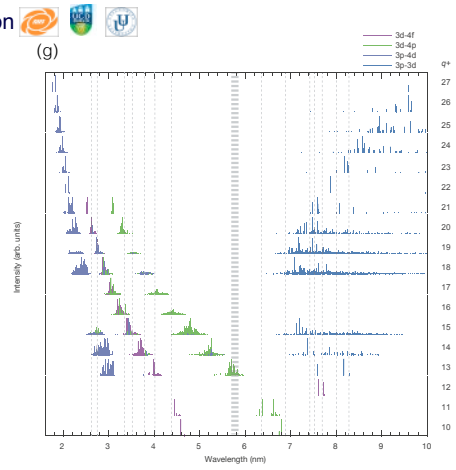
C. HULLAC calculation

(f)

Table.1. Zr ionization energy

q+	configuration		Ionization Energy (eV)
27	[Ne]3s^{2}3p^1	$^2P^o_{1/2}$	(1392$_{ex}$)
26	[Ne]3s^{2}3p^2	$^3P_2$	(1344$_{ex}$)
25	[Ne]3s^{2}3p^3	$^4S^o_{3/2}$	(1277$_{ex}$)
24	[Ne]3s^{2}3p^4	$^3P_2$	(1205$_{ex}$)
23	[Ne]3s^{2}3p^5	$^2P^o_{3/2}$	(1144$_{ex}$)
22	[Ne]3s^{2}3p^6	$^1S_0$	(1092$_{ex}$)
21	[Ar]3d^1	$^2D_{3/2}$	(922$_{ex}$)
20	[Ar]3d^2	$^3F_2$	(863$_{ex}$)
19	[Ar]3d^3	$^4F_{3/2}$	(803$_{ex}$)
18	[Ar]3d^4	$^5D_0$	(745$_{ex}$)
17	[Ar]3d^5	$^6S_{5/2}$	(690$_{ex}$)
16	[Ar]3d^6	$^5D_4$	(622$_{ex}$)
15	[Ar]3d^7	$^4F_{9/2}$	(573$_{ex}$)
14	[Ar]3d^8	$^3F_4$	(520$_{ex}$)
13	[Ar]3d^9	$^2D_{5/2}$	(470$_{ex}$)
12	[Ar]3d^{10}	$^1S_0$	(426$_{ex}$)
11	[Ar]3d^{10}4s^1	$^2S_{1/2}$	(236$_{ex}$)
10	[Ar]3d^{10}4s^2	$^1S_0$	(214$_{ex}$)

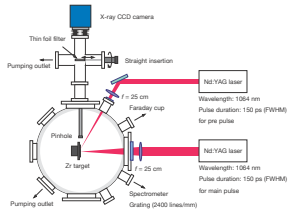
(g)



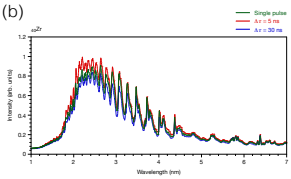
3. Spectral difference by dual lasers

A. Spectra

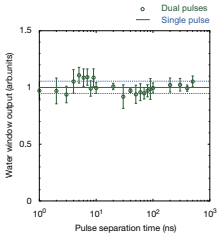
(a)



(b)



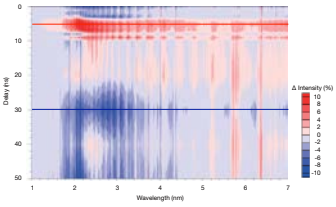
(c)



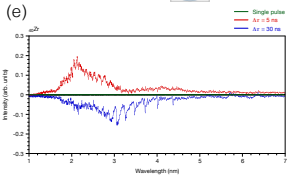
(a) Setup
(b) Spectra
(c) Water window output
(d) Difference spectra 2D map
(e) Difference intensities
(f) Emissivity
(g) Opacity
(h) Source size
(i) Source diameter vs pulse separation time

B. Difference spectral intensities to the single pulse

(d)

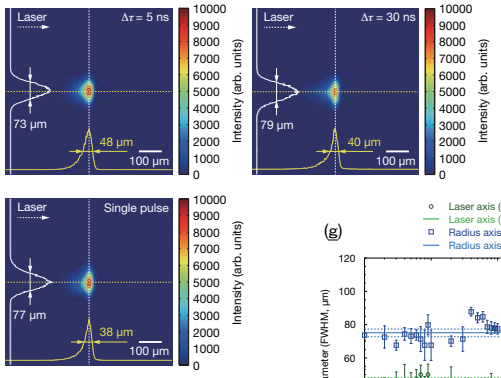


(e)

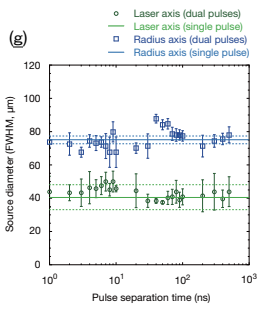


C. Water window soft x-ray source size

(f)



(g)



4. Summary

We have characterized the absorption spectral structure of dula laser-produced highly charged zirconium plasmas in water window soft x-ray spectral region due to the opacity effects in the recombination phase. Emissivity and opacity have been also evaluated in Zr plasmas.

Acknowledgements

A part of this work was performed under "Project for Bio-Imaging and Sensing at Utsunomiya University" from MEXT. One of the authors (T.H) also acknowledges support from The Canon Foundation, Research Grant (Basic Research) on TEPCO Memorial Foundation. The UCD group was supported by Science Foundation Ireland International Co-operation Strategic Award 13/ISCA/2846.